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mated with brown animals which invariably lack agouti. There were produced 15 young, of which 7 were yellow, 5 agouti and 3 black or brown. Evidently the yellow parent transmitted non-yellow (black or brown) in 5 cases associated with agouti, and in 3 cases not so associated. On Sturtevant's hypothesis all non-yellow young should have been agouti.

C. C. LITTLE

LABORATORY OF GENETICS,
BUSSEY INSTITUTION, HARVARD UNIVERSITY,
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PHYSICAL ANALOGIES OF BIOLOGICAL PROCESSES

Two schools or methods of thinking of heredity and other general problems are recognized among biologists. Some hold that all biological phenomena are to be explained in terms of physical and chemical properties of unorganized matter. Others are inclined to believe that the activities of living matter represent agencies or relations not shown in the inorganic world. The first view has been called materialism, the second vitalism.

These distinctions are not as important as sometimes supposed, because of our inadequate knowledge of the properties of matter, whether organic or inorganic. The materialistic view may be said to have a practical advantage in encouraging the investigation of the physical and chemical phenomena of the organic world, but vitalism may claim at least an equal advantage in permitting the recognition of facts that lie on the other side of the biological field, where the analogies of physics and chemistry find little or no application. Thus the specific constitution or speciety of living matter, the fact that organisms maintain their existence and make evolutionary progress only in groups of individuals united into specific networks of descent, involves the recognition of a condition or property quite foreign to the usual conceptions of the physicist or the chemist. Yet this universal condition of speciety must be considered as a general basis or background for any strictly biological study of the organic world. We may count, weigh, measure or analyze the bodies and activities of organisms from as many other standpoints as we please, but it is idle to draw general biological conclusions from any merely mathematical or physical data. The true biological significance of statistical and physical facts has to be determined by biological analysis.

As long as physical and mathematical analogies add something to our comprehension of biological facts they are entirely desirable and legitimate. Even an incomplete and inadequate analogy may be very useful for descriptive purposes. But when the elaboration of an analogy interferes with perception of the fact it is supposed to elucidate the limitations of the method become apparent. This danger may be illustrated by a recent attempt to define biological evolution in physical terms.

In the minds of most of us the term "evolution" is associated probably more closely with the biological than with the physical sciences. Yet the concept is essentially physical in character, and is definable in exact terms probably only in the language of physics. For in its last analysis we may define evolution as *the history of a material system undergoing irreversible transformation.* To the physicist, therefore, the study of evolution is essentially the study of irreversible changes, and the law of evolution is the law of increasing entropy, or, more generally, of the increasing probability of the successive states of any real material system.[1]

Whether such definitions have any practical advantage as aids to further investigation may be questioned. Exact terms are of little use in biology unless they are also concrete, that is, unless they convey an idea of something that can be seen, or at least imagined. Physicists are much more tolerant of mathematical and metaphysical abstractions. The habit of using abstract conceptions often leads to the announcement of wonderful discoveries that resolve themselves, on closer inspection, into purely metaphysical manipulations of terms. Thus it is considered one of the notable services of a "supreme biologist" that he should have identified chemical reactions with organic tropisms, tropisms with instincts, instincts with morals, and then predicted a chemical analysis of morality.[2]

Such inferences only show that the vocabulary has been thrown into solution, not that any concrete insight has been gained. Physical terms can be set into formulæ as mystical as a wizard's incantations. Sleight of hand is discredited, but verbal miracles are still performed with "scientific principles." When so-called physical science runs to seed in antinomies it becomes plain that we are back again in the vicious circles of metaphysical deduction.

To describe biological evolution as a process of irreversible transformation seems especially inappropriate because it is of the very nature of biological changes to be reversible, or recurrent in each generation. Only by limiting the idea of evolution to changes in the underlying mechanism of transmission could the specification of irreversibility be made to apply.

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[1] Lokta, Alfred J., "Evolution in Discontinuous Systems," *Journ. Wash. Acad. Sciences,* Vol. II, No. 1, 1912, pp. 2–4.

[2] "The Chemistry of Morals," *Current Literature,* 52: 180, February, 1912.

Nor is there justification for considering biological evolution under the caption of discontinuous systems. Variations, in the sense of changes of expression of characters, are often discontinuous, but this does not mean that evolution is discontinuous. Some biologists have supposed that new characters constitute new species, but in reality we have to think of the old species as developing the new characters instead of the characters originating the species. As long as species are considered only in a statistical or biometrical sense, the existence of different species will appear to rest on evidence of mathematical discontinuity. But for any truly biological purposes such discontinuity must be considered as a result of evolution, rather than as a condition or cause of evolution. All characters, in the evolutionary sense of the word, are first presented as differences among the members of species. Such differences are always variable, or alternative in expression, which is another way of saying that they are reversible; that is, they appear and disappear, or are expressed in various degrees, in the different individuals belonging to the same specific group.

The phenomena of mutation represent discontinuity among members of the same species, rather than differences between species. Natural species seldom have the same kinds of differences as mutative variations. The theory that species originate by mutative changes of characters is well calculated to deceive physicists and biometricians who are not familiar with the facts of diversity in natural species. Ortmann diagnosed the difficulty with the mutation theory by saying that DeVries does not know what a species is. Familiarity with species is seldom considered as a necessary qualification for the study of evolution and heredity. Indeed, most of our physiological and mathematical biologists have dismissed species as something too indefinite for their purposes. They prefer to begin with a definition that can be stated in exact terms and turned into figures or formulæ. The casual choice of words like irreversible or discontinuous becomes fraught with a vast importance, seldom mitigated by any appreciation of the fact that most of the language of biology is merely descriptive and comparative, and hence to be understood only in relative senses.

If we cut through a tree top it will appear that the branches are discontinuous, but if we follow individual branches this effect of discontinuity is lost. For some purposes the process of growth might be described as continuous or gradual, and for other purposes as discontinuous, for there are daily interruptions or variations in the rate of growth. Darwin compared the evolution of species to the growth of branches on a tree. Theories that would supplant Darwin's conception of continuity in the evolution of species are not based on equal familiarity with the facts. Constructive evolutionary progress comes by gradual changes in the characters of species, not by saltatory transformations of one species into another. That albinism and other defects appear as mutations and show Mendelian inheritance does not destroy or even conflict with the evidences of continuity in the evolution of species.

The many different applications that can be made of such terms as continuity or discontinuity show how little is gained by the choice of any particular statement of biological facts as a basis for deduction or mathematical elaboration. That new facts can be learned by syllogizing is no longer believed. Is more to be gained by turning syllogisms into mathematical formulæ? Even when physical analogies can be more definitely drawn the biological relations of the facts seldom permit any complete application of mathematical methods of thought.

Taking evolutionary deviations into account, the recurrent life cycles of organisms could be considered as spirals and this might appear to bring them within the range of mathematical treatment. Yet no regularity of form could be ascribed to such spirals, for evolutionary intercalations of new characters are not merely additions at the ends of definite series, but are likely to intervene in any part of the life cycle. Moreover, such intercalations are made without throwing the remainder of the cycle out of adjustment.

From the historical standpoint evolution may be presented as a series of transformations, but from the standpoint of heredity the results must be treated as permanent and coexistent, not merely as successive reactions. Each member or part of the cycle must be supposed to carry the determinants or potentialities, the powers of reproducing every other part. And we know further that these potentialities continue to be carried in latent or recapitulated form, even after they have ceased to come into normal expression. In other words, the biological system retains latent possibilities of reversion, the maps, as it were, of courses of development long since abandoned. Even though the characters be considered as irreversible in the sense of having permanent transmission they are subject nevertheless to endless vicissitudes of internal and external relations that influence the expression of characters.

Thus the life-cycle spiral is not a single line, but is resolved into a vast multiplicity of lines, tracing back to all the different ancestors. The expression relations of the characters can be analyzed, in a measure, by breeding experiments and by comparing behavior under different conditions, but the nature of the system is such that its most permanent and stable adjustments are those that are farthest removed from the influences of the environment. Hence the futility of mathematical treatments that attempt to combine environmental vicissitudes with the entirely inconsistent facts of biological evolution. Instead of evolution representing a law of increasing probability of successive states, the contrary would be more nearly true. The more specialized the organization the less the probability of passing to another state. Thousands of species are extinguished to one that develops a higher type of organization. Instead of evolution representing a summarized result of environmental influences, it is rather to be considered as a history of ways of avoiding such influences. There are no facts to show that evolutionary progress is caused by environmental agencies or by internal mechanisms. The causes of evolution lie in the structure of the species.

The crowning complexity of the biological system is that the life-cycle spirals do not remain separate and distinct from each other, but are thoroughly interwoven to form a continuous network of descent for each species or group of interbreeding individuals. It may be that a mathematical formula could be made for a spiral wire mattress or a Turkish rug, but this would afford only a faint analogy for the complications that attend the evolution of a species. To describe a species as a network of descent may be only a figure of speech, lacking altogether in mathematical exactness, but it is a way of pointing out a concrete biological fact. When the facts are essentially complex any statement that conceals or disregards the complexity is to that extent specious and misleading.

Many of the results of evolution can be described in simple terms of quantity or sequence, but to consider such statements as definitions, or to suppose that they confer any special license for mathematical elaboration, is to disregard the true nature of the facts and problems of biology. For purposes of physics or chemistry individual plants or animals may be considered as machines, but for purposes of evolution the whole species represents the machine in which the patterns of new characters are woven. If mathematical elaboration is to serve any useful purpose in showing how evolutionary progress is made the nature of the machine, the specific organization or speciety of the organic world, must be recognized.

O. F. COOK

WASHINGTON, D. C.,
March 15, 1912

ON FAIRNESS AND ACCURACY IN SCIENTIFIC REVIEWING

TO THE EDITOR OF THE AMERICAN NATURALIST: Any one who takes a turn at the critical hoe with the object of ridding the biological field of some of the noxious products of fertile imaginations untrammeled by quantitative facts must expect just the sort of attack which appears in your recent issue (AMER. NAT., March, 1912, p. 165).

1. Dr. Spillman has not felt the purpose, methods or results of my paper worth statement. Instead he illustrates by it the "noticeable degree of correlation between positiveness of statement and inaccuracy of statement." And for the reason: "in Dr. Harris's paper he represents me as having cited the fact [*sic*] that these genotype norms [*sic*] form a frequency curve [*sic*] as proof of the genotype hypothesis [*sic*]."

One excuses the minor inaccuracies and would be glad to pass over the whole assertion with the simple comment that it seems unjust, but to protect himself against further accusations of "inaccuracy of statement" he must add, it is not true.

What I did do was to cite Dr. Spillman among three others in substantiation of the opening sentence, "Several times recently we have been told that the means of a character in a series of pure lines form a 'Quetelet's curve.' " I based this on his statement concerning pure lines, "They not only do not differ in all their characters as the *Œnothera* mutants do, but their norms present a regular series coming under 'Quetelet's Law' " (AMER. NAT., Vol. 44, p. 760). Surely no injustice has been done so far. Later in the paper I did make a statement (which still holds true) remotely similar to the one quoted above, and said specifically "A case in point is a paper by Roemer." There was no reference whatever to Dr. Spillman—expressed, suggested, insinuated, intimated, implied, . . . or intended.

2. Although it is clearly without any justification, the foregoing criticism would, it seems to me, have gained in strength by specificity and moderation of statement. But Dr. Spillman con-